

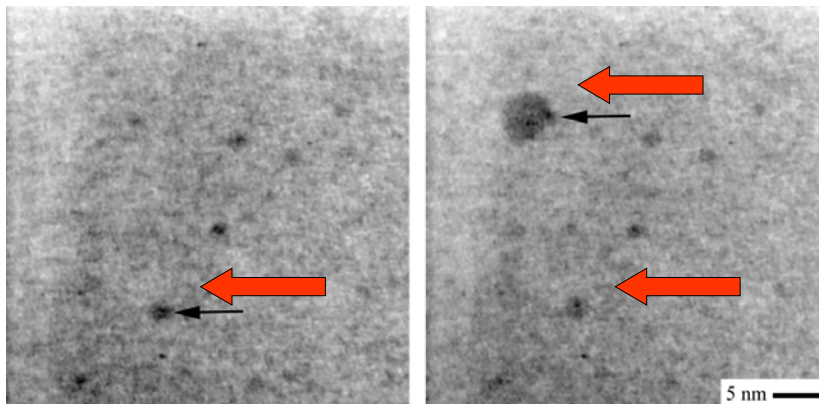
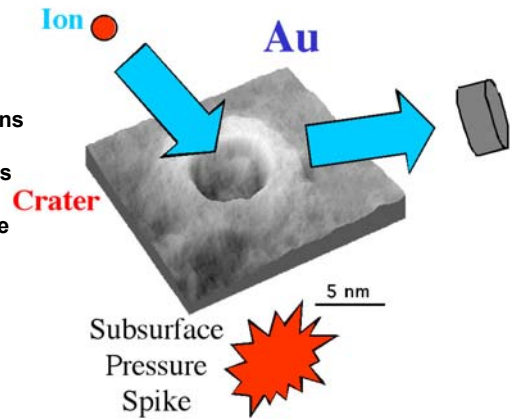
Single Ion Impacts: Craters and Nanoparticle Ejection

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Decades of radiation damage research concentrated on the accumulative effects of irradiation without detail information on individual displacement events. Development of transmission electron microscopy equipment and techniques has provided the ability to experimentally resolve individual displacement events during in situ ion irradiations in the IVEM-Accelerator Facility at Argonne National Laboratory.

Individual ion impacts on dense metals result in dense, near-surface displacement events involving several tens of thousands of atoms that can result in surface craters and holes. Continuous TEM observation reveals that craters are reshaped or annihilated by plastic flow associated with subsequent ion impacts. Craters are also annihilated by surface diffusion of irradiation induced defects.

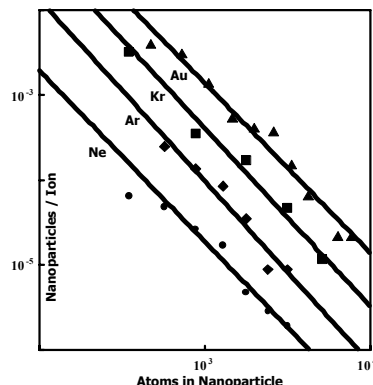
In addition to crater formation, a previously unknown process associated with the ejection of material from irradiated surfaces has been discovered. Au sputtered by ion impacts was simultaneously collected and viewed by TEM on an electron transparent carbon foil. A major constituent was nanoparticles deposited after ejection by single ion impacts. Individual Xe ions eject Au nanoparticles with an average diameter of approximately 3 nm but with diameters as large as 7 nm. Ejection of nanoparticles and crater formation are caused by single ion impacts that are capable of producing dense displacement cascades in the near surface region of a specimen. Ejected nanoparticles can make a significant contribution to sputtering. In the case of Au, nanoparticle emission contributes approximately 15 % to the total sputtering yield for 400 keV Xe ions. This is a general phenomenon that has been observed for a wide range of materials [Cu, Ag, Pt, W, Pt/Cobilayer] and can be used for nanoparticle processing.



Nanoparticles ejected from Au by the impact of single Xe ions. Images are separated in time by 1/30 sec

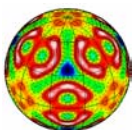
The size-distributions of nanoparticles yield an inverse power-law with an exponent of -2 that is independent of ion type and energy. The inverse-square dependence indicates that the nanoparticles are formed by shock waves impacting and ablating the surface, as predicted by the model of Bitensky and Parilis. Observation of the ejection of stable nanoparticles is a surprise because the energies involved in the ion-target collisions are three orders of magnitude larger than the binding energies holding the clusters together. This is resolved by realizing that the shock wave does not impart energy to individual atoms but to the particle as a whole.

Size distributions of Au nanoparticles ejected by different ion masses. Note that the sizes vary as the inverse square of the number of atoms in the particle independent of the ion mass.



Since shock-wave ejection acts in picoseconds, it ejects unaltered bits of the surface that are not heated. Nanoparticle deposition is easily controlled with adjustable ion-beam parameters. It is even possible to write with nanoparticles controlling the deposition area through masking. Shock wave ejection allows production of complex nanoparticles such as layers of different materials. This process is compatible with silicon device fabrication technology and can form the basis for production of advanced magnetic and optical devices.

Nanoparticle Ejection from Au induced by Single Xe ion impacts, R. C. Birtcher, S. E. Donnelly, and S. Schlutig, Physical Review Letters, 2000. 85(23): p. 4968-4971.



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